Towards a Cleaner Vehicle Fleet: The Dynamics of the Swedish Biofuel System

SANCHES-PEREIRA, A. [a*], GÓMEZ, M.F. [a]

a. KTH Royal Institute of Technology, Sweden

**Corresponding author, perei@kth.se*

Abstract

The study's overall objective is to present how the development of the Swedish biofuels system impacts the achievement of the European Union's target of 10% of renewable fuels in transport by 2020 and the establishment of a vehicle fleet independent of fossil fuels by 2030. The methodological approach is based on a combination of forecasting and backcasting scenarios. This cross-analysis is used to relate one set of data with others in order to identify gaps between the potential energy use in the Swedish domestic transport sector with the country's desired targets. Our analysis shows three gaps related to i) infrastructure and management capabilities for local biofuel production, ii) policy instruments to trigger systemic changes to reduce dependence of imports, and iii) investment decisions. In order to bridge those gaps, policymakers have to decide on how to steer the system's development not only by combining different pathways between different growth patterns of the Swedish biofuel system but also deciding either to apply supply or demand pressures onto the system as driving forces. These choices have to be taken in a very short-run in order to shape the development of the Swedish biofuel system away of failing the target of establishing a vehicle fleet independent of fossil fuels by 2030.

Keywords: Biofuels, bioenergy systems, transport sector, Sweden.

1. Introduction

The Directive 2009/28/EC or Renewable Energy Directive (RED) as it is called aims to promote the use of energy from renewable sources by setting a common vision for the European Union (EU). Each Member State has to achieve a specific target so that, as a whole, the EU shall have 20% of the total energy based on renewables by the year 2020. The Directive also contains a roadmap to cut down 20% of the EU greenhouse gases emission and a framework for reducing the region's oil dependence in the transport sector, which is illustrated by the target of 10% of renewable fuels in the same period. Although the EU is expected to fall short on the renewable fuels' target, Sweden is expected to reach beyond it(European Union, 2009).

In 2011, the final energy use in the Swedish domestic transport sector amounted to 94 TWh or 16% of the total final energy supply in the country, of which renewable fuels comprised 7.64 TWh. The share of renewables in the domestic transport sector has more than three-folded in the last decade, from 2.5% in 2000 to approximately 8% in 2011. In a business as usual scenario, Sweden may exceed its 10% target for 2020 by approximately 2%, with bioenergy amounting to approximately 12 TWh

(Swedish Energy Agency, 2012a; Swedish Energy Agency, 2012b; Swedish Energy Agency, 2011a; Swedish Energy Agency, 2009; Swedish Energy Agency, 2012c). The Swedish government's vision is to have a vehicle fleet independent of fossil fuels by 2030(Government of Sweden, 2010). As a result, this study aims to present how the development of the Swedish biofuels system impacts the achievement of 10% of renewable fuels by 2020 and the establishment of a vehicle fleet independent of fossil fuels by 2030. The research question is: *Is there a "gap" between desired targets and the development trend of the biofuel use in the Swedish transport sector?*

In order to answer this question, the study uses a combination of forecasting and backcasting scenarios. The idea behind is to match the potential energy use in the Swedish domestic transport sector with the country's desired targets. The study relies on raw data collected from governmental institutions and statistical database such as Statistics Sweden, Swedish Energy Agency Swedish Transport Administration, Swedish Bioenergy Association, and International Energy Agency. Academic publications and reports are used to complement and validate processed information. The methodological steps includes i) identification of the development trend in the current Swedish biofuel system using forecast analysis against desired scenarios and ii) calibration of target scenarios using cross-analysis between forecasting and backcasting scenarios.

The study is divided into three main sections. The first section introduces the research's motivation and the methodological steps. The second section highlights the dynamics of the Swedish biofuel system, the composition behavior of the country's fleet, and the system's development trend. The final section presents the concluding remarks about the current development of the Swedish transport sector towards a vehicle fleet independent of fossil fuels.

2. The Swedish biofuel system

Currently, biodiesel is the frontrunner among the renewable energy carriers used in Sweden. Its contribution to the renewable energy mix used in the domestic transport sector is roughly 36%, closely followed by bioethanol with around 32%, renewable electricity (i.e., generated by biomass-, hydro- and wind-power) with 22%, and upgraded biogas with near 10%(Swedish Energy Agency, 2012a; Swedish Energy Agency, 2012b; Swedish Energy Agency, 2012c; Svenska Bioenergiföreningen, 2012). Obviously, the total use of renewable fuels is increasing. However, the development trends vary for the different fuels reflecting changing directions in policies. In addition, its flexibility would increase the likelihood of meeting the desired targets. As a result, fuel options are becoming more diversified as their share becomes well distributed. Note that we assume multi-carrier energy systems based on renewables as a more reliable energy system than fossil fuel based systems in an increasingly carbon-constrained world.

Understanding the allocation of renewable energy carriers is also important because it provides an outlook of the role of each one of these energy carriers on meeting the 10% target of renewable fuels in the Swedish domestic transport sector in the short run (e.g., 2020). One interesting fact observed in this contribution outlook is that renewable electricity has maintained its amount of energy provided rather stable (e.g., around 2 TWh) despite dropping its position as the key renewable energy carrier during the period of 2000 to 2011. In fact, renewable electricity slightly provides less energy today than it did in 2000. Nevertheless, electricity is expected to gradually regain its position as an important energy carrier in the long run (e.g. 2050), particularly in passenger cars.

According to Sköldberg*et al.* (2010) the amount of electricity needed by 2030 to supply a growing fleet of electric vehicles (EVs) would increase from today's 3 TWh to around 7 up to 9 TWh(Sköldberg, et al., 2010). Also, the development of EVs pushes the development of conventional vehicle towards more efficient engines with lower emissions and creates a competition where everyone would like to offer an attractive product. For example, currently "green cars" in Sweden have emissions bellow 120g of CO_2

per kilometer and they are expected to get even lower (e.g., "super-green cars" have emissions bellow 50g). Assuming a BAU scenario – in which the final energy use in the Swedish domestic transport sector would account for about 108 TWh by 2030 and that EVs are not going to stimulate electricity generation in the median run (e.g., before 2030) – and the share of renewable electricity is kept under current values, the amount of renewable electricity in 2030 would be around 2 TWh or 12% of the renewable energy used for domestic transport in Sweden(Sköldberg, et al., 2010). Meaning, around 13 TWh would need to be covered by biofuels, which corroborates their role as key energy carriers to achieve a vehicle fleet independent of fossil fuels.

Turning now towards a more optimistic perspective, Sköldberg*et al.* (2010) present two new scenarios that involve substantial changes in the Swedish energy mix used in the domestic transport sector. The first scenario, called Efficient (EF), assumes that vehicles in general are more energy efficient by 2030. It also assumes that the amount of fossil fuels decreases from 90% to 40% of the total energy use in the transport sector in the same period. In this context, the amount of energy used in Sweden would be cut by almost 50% when it is compared to the reference scenario BAU. Meaning, that roughly 30 TWh or 54% would be covered by renewable energy, in which biofuels still remain the key energy carrier with about 87% share of the total renewable energy used in the country's domestic transport. The second scenario is based on a fuel switching (FS) approach, in which is assumed that vehicles kept the current efficiency. In this case, it is crucial increasing the shares of biofuels and electricity in order to reach the same level of fossil fuel use as in the previous scenario. Again, biofuels play a significant role towards the vision of achieving a vehicle fleet independent of fossil fuels by 2030. In this scenario, biofuels would account to about 89% share of the total renewable energy used in the domestic transport(Sköldberg, et al., 2010). Table 1 summarizes these potential scenarios for 2030 and shows – without a doubt – that biofuels are important energy carriers on helping Sweden to achieve a vehicle fleet independent of fossil fuels in each one of these scenarios(Sköldberg, et al., 2010). It is important to notice that none of the potential scenarios provides information about the contribution of bioenergy carriers in the bioenergy supplied. Meaning, there is no indication on how diversified and well-distributed bioenergy carriers could be in the system in order to build up security and reliability levels.

Table 1: Energy consumption in the Swedish domestic transport sector for potential scenarios in 2030.

Energy Carrier	***BAU***		***Efficient (EF)***		***Fuel-Switching (FS)***	
Fossil fuels	91.9 TWh	85%	21.9 TWh	40%	21.9 TWh	31%
Biofuels	***13.4 TWh***	***12%***	***25.8 TWh***	***47%***	***39.7 TWh***	***56%***
Electricity*	3.2 TWh	3%	7.0 TWh	13%	9.1 TWh	13%
Total	**108.5 TWh**	**100%**	**54.7 TWh**	**100%**	**70.7 TWh**	**100%**

* *The study assumes that electricity values correspond to the current total share production of fossil fuels (44%) and renewables (56%) based on data from Swedish Energy Agency (2012) and Svebio (2012).*

2.1 Swedish biofuel system's dynamics

System dynamics thinking began in the mid-1950s as a tool to improve understanding of complex industrial processes. The approach utilizes drivers within the system, which are represented as information-feedback processes, to model a feedback structure closely tied to system performance. Since then, it has been applied to solve a wide range of system's problems, from industrial and organizational to policy-oriented issues(Sterman, 2000; Bush, et al., 2008).

Bioenergy systems can be seen as a classic system dynamics case because their problems tend to share four important characteristics(Bush, et al., 2008):

- They are dynamic, which implicates change over time.

- They involve multiple stakeholders with diverse interests, ranging from farmers, entrepreneurs, and consumers to policymakers, whose interactions can impact the system's overall performance.
- They present interdependencies with different systems and processes, which are critical to their overall performance (e.g., competition among food, fiber and fuel production).
- They can be challenging to identify communication issues, structural components, and leverage points.

Translating these four characteristics into a single statement about biofuel systems means that a larger use of biofuels – bioethanol, upgraded biogas, and biodiesel – depends on resource availability and the establishment of effective production chains that can turn them into competitive alternatives among conventional options such as gasoline, natural gas and diesel.

Therefore, using a system dynamics model provides useful information about the behavior of the Swedish biofuel system. It can help to identify underlying structural components and its interactions, which could be used as leverage points to steer and control the system's development. Fig.1 illustrates the behavior of bioenergy contribution per type of biofuel to the Swedish domestic transport in the last decade.

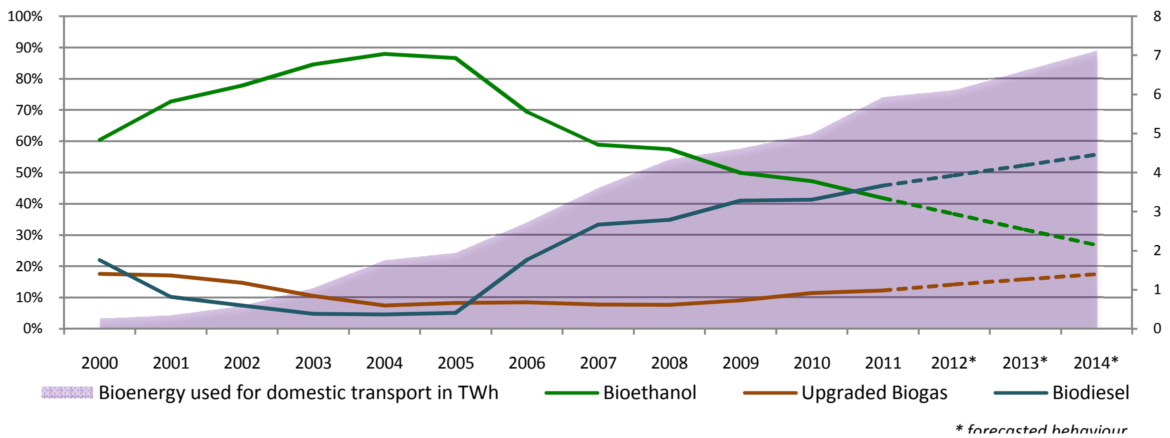

Fig.1: Behavior of bioenergy carrier contribution per type of biofuel to the Swedish domestic transport.

The area indicates the amount in TWh of bioenergy used in the sector and the amounts are displayed in the right *y*-axis. Lines represent the biofuel share or its contribution to the bioenergy supplied and the values are displayed in the left *y*-axis. Dashed lines are forecast values based on linear regression with coefficients of determination (R^2) ranging from 0.9346 to 0.9989. The figure shows that bioethanol was the key bioenergy carrier in 2000 with 60% contribution of the total bioenergy used (e.g., 0.26 TWh) by the Swedish fleet in that year. In 2011, the bioenergy used was about 6 TWh and the behavior of the system changed. Biodiesel became the key bioenergy carrier with 46% contribution as compared to bioethanol (e.g., 42%) and upgraded biogas (e.g., 12%) (Swedish Energy Agency, 2012a; Swedish Energy Agency, 2012b). As is evident from Fig.1, bioenergy contribution is continuously increasing. It has grown 22-fold from 2000 to 2011. The same has happened to bioenergy carriers but at a lesser rate. The contributions of bioethanol and upgraded biogas have grown approximately 15-fold each. Yet, biodiesel broke the trend and suffered a rapid increase. Its contribution has increased 47-fold in the same period, from 0.06 to around 3 TWh. The figure also suggests that if the current behavior continues – meaning, the same pattern is bound to continue in the future – the bioethanol contribution would decrease further, which is pictured by the dashed lines. In fact, the forecasted bioethanol contribution would decrease from today's 42% to 24% already in

2014. This outcome is led by the increasing share of upgraded biogas with 14% and biodiesel accounting to more than half of the forecasted bioenergy use in the Swedish domestic transport sector in that same year(Swedish Energy Agency, 2012a; Swedish Energy Agency, 2012b).

Another interesting element observed in Fig.1is the symmetric shape between the bioethanol and biodiesel lines, which indicates a very strong relationship between their systemic behaviors. One way to validate this assumption is to identify the same very behavior in the country's fleet development in order to confirm if what is happening is a fuel substitution process or efficiency improvements in vehicles.

2.2 Composition behavior of the Swedish fleet

Nowadays, the Swedish fleet accounts to around 5 million vehicles, in which the composition can be assumed as 88.67% personal cars, 11.05% lorries, and 0.27% busses if motorcycles, moppets and other vehicle categories are not included. This study focused only on vehicles fueled by gasoline, diesel, bioethanol, and gas fuels (e.g., admixture of natural gas and upgraded biogas)(Trafikanalys, 2012; TransportNäringen i Samverkan, 2010). Other categories such as electric and hybrid vehicles are not included in the analysis because of their few numbers and low impact on the relationship between the bioethanol and biodiesel fuels during the period of 2000 to 2011.

Data set related to the Swedish fleet composition is presented in Fig.2, in which the fleet is organized per type of vehicle and fuel in the last decade. Interestingly, the graphs show similar symmetric behavior happening between the numbers of gasoline and diesel vehicles on the data set related to personal cars and lorries. However, the same behavior does not occur on data connected to busses despite gasoline vehicle numbers persist on waning(Trafikanalys, 2012; TransportNäringen i Samverkan, 2010). In this particular case, the application of gas fuel is increasing rapidly and pushing the country's production of biogas. In fact, around 50% of the produced biogas in 2011 was upgraded and used as vehicle fuel in Sweden(Swedish Energy Agency, 2012d).

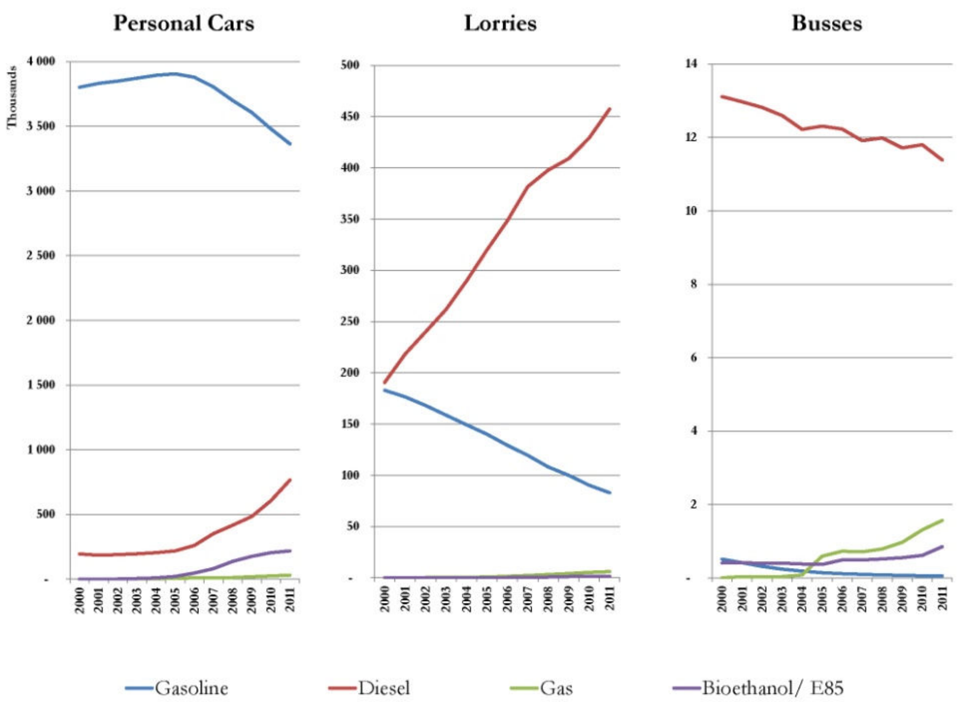

Fig.2: Swedish fleet composition per type of vehicle and fuel.

The figure clearly shows that gasoline vehicle numbers are decreasing and being replaced; validating that what is happening is a fuel substitution process in the fleet. This is a result of many policy instruments based on low-carbon emissions, which have been affecting the development of the transport sector in Sweden during the last years(Swedish Energy Agency, 2011b). Important information is that dependency on diesel is increasing. In fact, lorries already are highly dependent on it. Meaning, a shortage of diesel would impact Swedish capability of bioenergy generation because several components of the bioenergy system are highly dependent on road transport and heavy-duty vehicles, such as machinery operation in the forestry sector and transport of raw materials from forests to fuel factories and of biofuels to heating plants (Swedish Energy Agency, 2011b). In this context, being capable of using low-admixture of biofuels without requiring technical adaptations in vehicles is an important factor not only to maximize biofuel penetration in the market but also to guarantee energy security, to reduce fossil fuel dependency by whatever means possible, and to meet sooner the target of 10% of renewable fuels in the domestic transport sector.

Without a doubt the composition behavior of the Swedish fleet has a direct influence on how biofuels are being consumed. For example, the decline of gasoline vehicle numbers in the fleet composition since 2005 has redirected the bioethanol delivering pathways. For the last ten years its 5% blended form was the common outlet but it has lately switched mainly to E85, which is a biofuel with 85% denatured bioethanol used by the flex-fuel vehicles in the country.

E85's role has fast increased since 2005 as a result of the National Climate Policy and the government's commitment to eliminate fossil fuel dependency by 2030(European Union, 2003; Government of Sweden, 2010). Another important component is the fact that the national association for the automobile industry gave its support to the initiative. However, the trend changed in 2009. A glitch in the behavior shows that consumers reacted rapidly to changes in policy and price fluctuations on fuels. In July 2009, the government removed the premium given for clean vehicles purchasing that lead to a sharp decline in vehicle sales in that year(Swedish Energy Agency, 2011b). Also, biofuel sales are highly dependent on the relative price of fossil fuels. For example, bioethanol consumption in Sweden is attractive until it costs up to around 74% of the gasoline price per liter(Pacini & Silveira, 2011). In addition, 2009 was a peculiar year for bioethanol consumption. In this particular year, the bioethanol average cost of one liter amounted to around 80% of the gasoline price per liter(Svenska Petroleum och Biodrivmedel Institutet, 2012). As a result, it abruptly reduced the E85's attractiveness. However, the systemic behavior has been stabilized and its current condition follows the trend prior to the glitch leading E85 to become the main bioethanol outlet by 2011.

In the case of biodiesel, the composition behavior of the fleet has influenced a fast growing consumption of the 5% blend of biodiesel, which corroborates not only the fuel substitution process in the fleet but also the fact that the Swedish dependency on diesel is increasing. It is important to address that efficiency improvements in vehicles are important, especially on reducing emissions, but they have not yet been influential in the consumption trend of biofuels.

Currently, the admixture of biofuels in Sweden is still 5% per volume of fuel but the Government allows blending up to 10% bioethanol in gasoline and up to 7% biodiesel in diesel since May 2011 (Svenska Petroleum och Biodrivmedel Institutet, 2012; Transportstyrelsens, 2012; Government of Sweden, 2011). The national association for the automobile industry has developed a list of car models that can run on 10% bioethanol (E10)(BIL Sweden, 2011). For diesel vehicles there is no need for a list containing manufacture recommendations since the technical admixture limit allows up to 20% biodiesel blend before considering modification to the diesel engine.

Despite low numbers in the fleet composition, gas fuel vehicles alongside with flex-fuel vehicles have gained momentum since 2005. In fact, they present the highest growth rate in the last decade when compared with gasoline and diesel vehicles.

Despite gas use in transport is increasing; the upgraded biogas' share of energy provided in the final use after taking up has been reduced during the last three years from around 63% to 59%(Swedish Energy Agency, 2012b). Curiously, the low variation in the share of energy provided found equilibrium in volume share ranging around 62% in the course of the same period. Besides meeting policy's targets, other important factors have contributed to push upgraded biogas as vehicle fuel. Its manageable integration into natural gas networks already in place and the fact that upgraded biogas is recognized as a reliable energy source provided a strong incentive. Around 50% of the produced biogas in 2011 was upgraded and used as vehicle fuel(Swedish Energy Agency, 2012d). In Sweden, the biogas use as transport fuel increased from 0.27 TWh in 2007 to 0.73 TWh in 2011. The usage has more than doubled the amount in a four-year period. Although 2007 established biogas as the leading fuel by the Swedish gas vehicle fleet according to the volume used, the leading fuel in terms of energy provided was still natural gas by a low margin of less than 1% over biogas. It is the year 2008 that sets the turning point. In that year, upgraded biogas provided around 60% of the energy used by the Swedish gas fleet and it has upheld the leading position up to now in terms of both volume and energy provided(Swedish Energy Agency, 2012b).

2.3 Development trends of the Swedish biofuel systems

The correlation between the information obtained from the bioenergy systems dynamics in the Swedish domestic transport sector and the composition behavior of the fleet made clear that biofuels significantly impact the country's ability to reach its desired targets. In fact, the analysis has shown the effectiveness of policies in place that is reflected in the continuous growth of biofuel use in transport. These important driving forces, the manageable integration of biofuels into distribution networks already in place (e.g., blended fuels), and the fact that biofuels are recognized as a reliable energy source provided a strong incentive to this very growth. However, it makes one wonders about how diversified and well-distributed biofuels would be by 2020 and 2030 and how reliable their development trends are. Aiming to answer that, the target scenarios were revisited and calibrated using the correlation results in order to match the current development trend of the Swedish biofuel systems with the potential scenarios. This calibrated set of data forecasts that by the year 2020 the final energy use in the Swedish domestic transport sector would account for around 101 TWh, from which biofuels would represent approximately 12 TWh. In this context, biofuel contribution may already exceed the Swedish target of 10% share of renewables in the sector by approximately 2% in a BAU scenario. Note that the target would be met without even considering the renewable electricity input that would raise further this very share.

Interestingly, the calibration forced us to revisit as well the behavior pattern of bioenergy carrier contribution presented in Fig.1. On the one hand, the correlation results validated the very strong relationship between the systemic behaviors of bioethanol and biodiesel. On the other hand, it contradicted the trendline showing that bioethanol contribution would diminish in the future. In fact, the development trend shows that bioethanol would keep on playing an important role and its contribution to the Swedish biofuel system would account to roughly 40%, closely followed by biodiesel with around 39% and upgraded biogas with near 21% in the year 2020.

For the year 2030, the bioenergy contribution in this calibrated set of data varies from a pessimistic 20% – instead of 12% assumed by Sköldberg*et al.* (2010) – to a highly optimistic 56% share of the total forecasted energy use in the Swedish transport sector.

Table **2** presents the adjusted potential scenarios in 2030 and the contribution per type of biofuel.

Table 2: Calibrated potential scenarios in 2030 and bioenergy contribution per type of biofuel.

Energy Carrier	***BAU***		***Efficient (EF)***		***Fuel-Switching (FS)***	
Bioenergy	21.9 TWh	20%	25.8 TWh	47%	39.7 TWh	56%
Bioethanol	***7.2 TWh***	***7%***	***8.5 TWh***	***15%***	***13.0 TWh***	***18%***
Upgraded Biogas	***6.3 TWh***	***5%***	***7.5 TWh***	***14%***	***11.5 TWh***	***16%***
Biodiesel	***8.4 TWh***	***8%***	***9.9 TWh***	***18%***	***15.2 TWh***	***22%***
Fossil fuels	83.4 TWh	77%	21.9 TWh	40%	21.9 TWh	31%
Electricity*	3.2 TWh	3%	7.0 TWh	13%	9.1 TWh	13%
Total	**108.5 TWh**	**100%**	**54.7 TWh**	**100%**	**70.7 TWh**	**100%**

** The electricity values correspond to the current total share production of fossil fuels (44%) and renewables (56%) based on data from Swedish Energy Agency (2012) and Svebio (2012).*

The table also shows that the energy system's reliability to meet the desired targets would increase because biofuel options would become much diversified as their shares are becoming more evenly distributed. Fig.3shows these development trends, in which lines correspond to the energy amount provided in TWh per type of biofuel and displayed in the left *y*-axis. Bars embody the bioenergy share in the Swedish domestic transport sector in percentage and the values are displayed in the right *y*-axis. Highlighted bars illustrate the development trends and their respective calibrated values for years 2020 and 2030 scenarios.

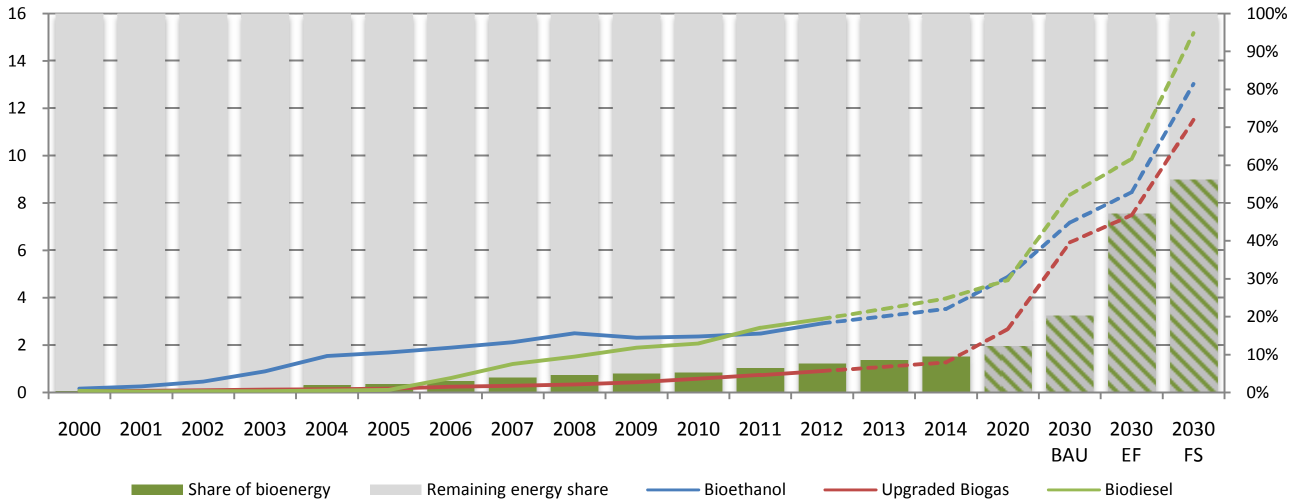

Fig.3: The development trends of the Swedish biofuel system.

It is important to mention that forecast was calculated using best-fit curved line based on polynomial regression for each one of the parameters and coefficients of determination (R^2) ranged from 0.94386 to 0.99789, which indicates a very strong relationship between *x* and *y* and a good fit of trendline to the estimated data. In addition, the results are based on the current admixture of biofuels in Sweden, which is 5% per volume of fuel. Meaning, increasing the blending would have a directly proportional impact on the dynamics of the system. It would most likely raise bioenergy contribution and, at the same time, change the bioenergy carriers' diversification and contribution. For example, biodiesel contribution would increase faster since its blending has the advantage of allowing up to 20% biodiesel before considering modification to the diesel engine. Note that blending, as mentioned previously, can be assumed as an important strategy that can enable Sweden meeting its targets sooner.

At first sight, the biofuel system's dynamics and its development trends reflected the effectiveness of Swedish policies to foster growth of bioenergy use in transport. Our estimative shows a growing, diversified, and well-distributed energy system that is building up security and reliability levels within the system itself. However, it is important to point out that a larger use of bioenergy depends on resource availability and establishment of effective production chains so as to substantiate this estimative. Thus, the interaction among structural components of the system and their causal links are key elements to understand whether there is a "gap" between desired targets and the current development of biofuel use in the transport sector or not.

3. Concluding remarks

It is important to stress that the results in the previous section present the potential behavior patterns of the Swedish biofuel system instead of providing a precise estimative. Yet, the analysis pushes the boundaries of our understanding of the Swedish Biofuel System by combining the results from forecasting and backcasting scenarios in a novel fashion. As a result, the potential behavior patterns can assist policymakers to understand the risks and vulnerability of the biofuel system towards a vehicle fleet independent of fossil fuels. That being said, we revisited the research question – *Is there a "gap" between desired targets and the development trend of the biofuel use in the Swedish transport sector?* – in order to draw our concluding remarks.

One step closer to the answer was to confirm the achievement of 10% of renewable fuels by 2020. Our analysis shows that bioenergy contribution would not just meet the target but reach beyond it even if the current development pattern is upheld, which is based on BAU scenario of the Swedish biofuel system. On the one hand, this outcome ratifies the effectiveness of Swedish policy measures in place. In fact, the country's policy framework not only recognizes biofuels as a reliable energy source but also explores their manageable integration into distribution networks as blended fuels. On the other hand, the Swedish biofuel system will continue depending on biofuel imports, which makes it periodically exposed to increased competition and pricing pressures.

In this context, the first identified gap is the lack of infrastructure and management capability related to local production, especially second generation biofuels. As a result, meeting the 2020 target will rely almost entirely on biofuel imports. Meaning, biofuel imports would keep on playing an important role in meeting the desired targets. In 2011, for example, 55% of the bioethanol and 60% of the biodiesel used in Sweden was imported mostly from France and Lithuania respectively(Swedish Energy Agency, 2012e).In order to change this pattern, current policy framework is not strong enough to trigger changes within the Swedish biofuel system. The reason behind this is the fact that the system itself is guided by a quite rigid structure and averse to changes based on current demand pressure instead of a supply pressure. Note that supply pressure onto the system relies on biofuel production increment to foster biofuel use and demand pressure depends on biofuel inventory reinforcement to meet fuel demands. This weakness shows the second identified gap that is the need for stronger policy instruments to trigger systemic changes to reduce dependence of imports and foster local production.

The third identified gap is investment downplaying caused by high level of uncertainty within biofuel systems. In general, bioenergy systems are still seen as risky by traditional and well-established investors, and this tends to hinder long-term investments in bioenergy infrastructure (i.e., biofuel production plants). The higher the uncertainty, the lower the investments made in biofuel infrastructure are. One of the current causes for uncertainty is related to the fact that biofuel systems in place have not yet been able to establish robust and clear sustainability criteria, especially related to land use changes, which could balance the interests of different stakeholders at national or international levels. This, in turn, affects confidence on biofuel availability and increases risks when it comes to quantity, quality, price, as well as demand volumes across the main supply sources. For example, the EU's draft directive, which limits use of crop-based biofuels in order to avoid a competition with food and fiber production, deals with indirect change in land use and biofuel standards that would affect the biofuel system as a whole. Regardless of the directive proposal does enter into legal force or not; it may still create uncertainties regarding the future development of the Swedish biofuel system. Therefore, it already impacts the system by making investors even more cautious and questioning the credibility of existing infrastructure on facing such challenge.

There is no doubt that biofuel systems were built on government support and incentives and they will continue relying on them to not only keep system stability but also to change their development in order to bridge the gaps and meet the desired targets without compromising security of supply and system's reliability. Our study presents a strong analytical framework that can be applied to monitor:

- *Improvement:* tracking development of the Swedish biofuel system by identifying and promptly addressing problems such as decreasing security or losing reliability.
- *Planning and forecasting:* cross-analysis results may serve as a progress check, which enables policymakers to determine whether they are meeting their goals or they need to revise markets' forecasts.
- *Competition:* the behavior patterns of system's development can compare their performance against system's benchmarks. Hence, they can identify weak areas (i.e., resource competition) and address them to sustain their competitive advantage in providing biofuels.

For the year 2030, our study shows those gaps have to be bridged as soon as possible. Policymakers have to decide on how to steer the system's development not only by combining different pathways between external-based or internal-based growth but also deciding either to apply supply or demand pressures. This choice has to be taken in a very short-run in order to shape the development of the Swedish biofuel system away of the potential BAU scenario that accounts to around 20% of renewable fuels. By doing so, the system would be away of failing the target of establishing a vehicle fleet independent of fossil fuels by 2030.

Although our analysis can oversimplify the problems, it builds knowledge and validates gathered information through a variety of sources. Hence, it is important to address that follow-up research is necessary to match the potential energy use in the Swedish domestic transport sector presented in our study with the Swedish resource potential and availability of local bioenergy carriers.

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